Controls on Subtropical Low Cloud as Diagnosed from AIRS, MODIS, and ECMWF-Interim Reanalysis

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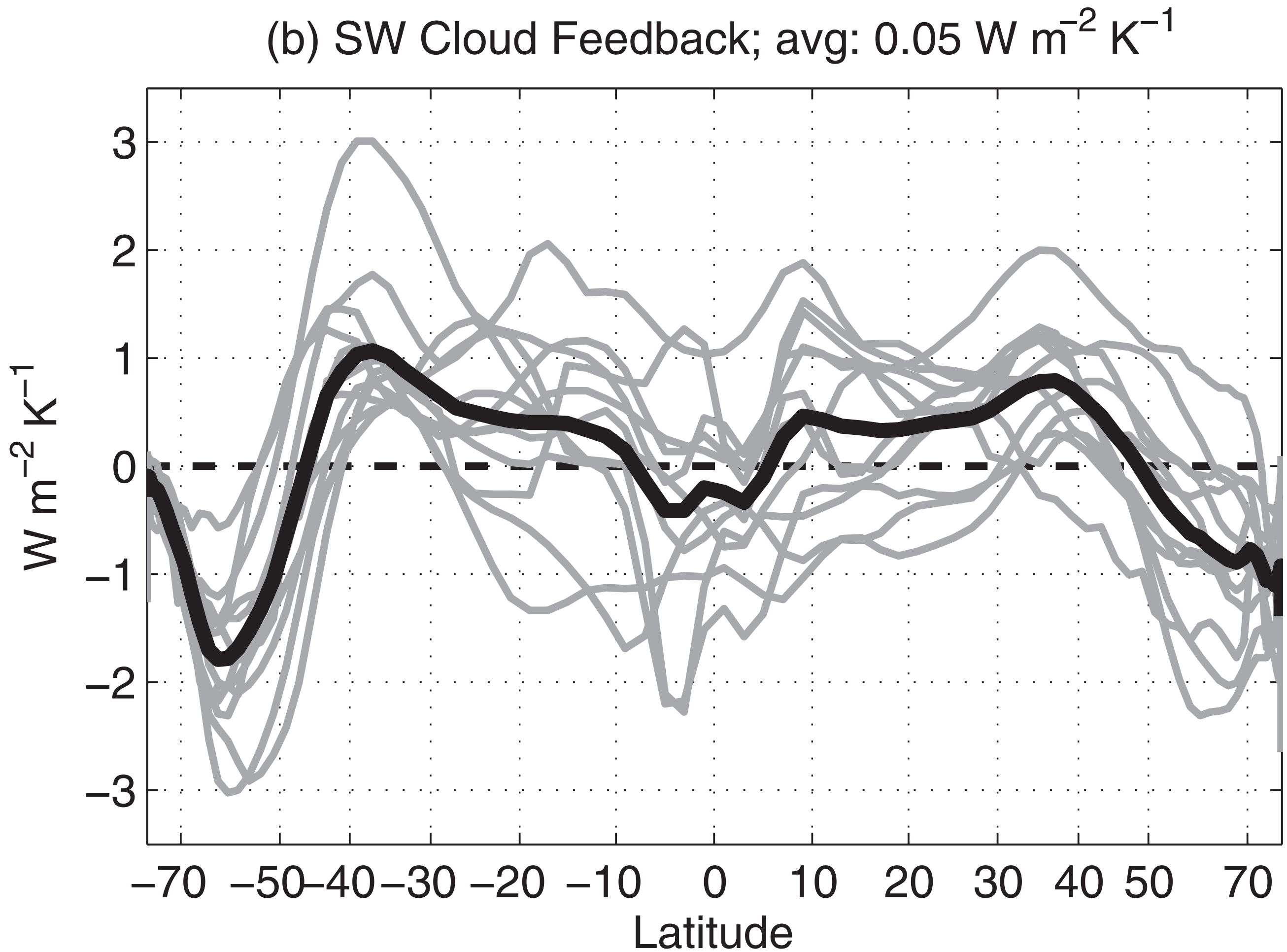
Outline

- Goal: Estimate subtropical SW cloud feedback from observations and natural variability in present climate
- Motivation
- Estimates of low cloud fraction change with warming
- Compare with GCMs, LES, and other observational studies
- *This work was done by Daniel McCoy, Ryan Eastman and Dennis Hartmann*

Motivation: SW Cloud Feedback Leading Uncertainty in GCMs



Zelinka and Hartmann, 2011

Goals of this Study

- Research Goals:
  - Estimate the dependence of Low Cloud Fraction (LCF) on large scale meteorological variables based on natural variability in the present climate
  - Use these relationships to estimate LCF changes for a 1K SST warming

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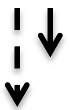
  - Estimate the dependence of Low Cloud Fraction (LCF) on large scale meteorological variables based on natural variability in the present climate
  - Use these relationships to estimate LCF changes for a 1K SST warming
- Caveats:
  - changes in GHGs or aerosols not considered
  - Relationships may be correlative, not causative

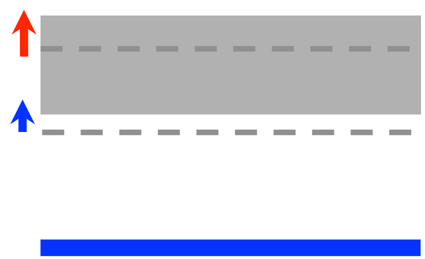
Mechanisms of LCF change

Dynamic

w550



Less subsidence

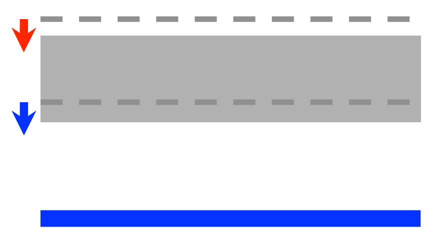


Sc top rises. More entrainment lifts cloud base.
Sc thickens.

Inversion strength

EIS

FT warms more than SST

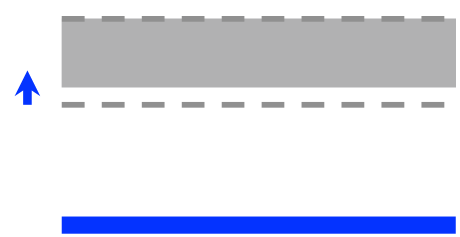


Stronger inversion reduces entrainment.
Sc top and base lower.
Sc thickens.

SST
RHFT
U10m

Thermodynamic

warmer SST
or drier RH



Larger surface – FT moisture difference allows thinner cloud to sustain same entrainment.
Sc thins.

Bretherton, submitted

Mechanisms of LCF change

Dynamic

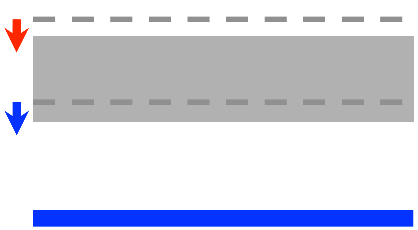
Less subsidence

w550

$$\mathrm{LCF} = a_1\mathrm{w550} + a_2\mathrm{EIS} + a_3\mathrm{SST} + a_4\mathrm{RHFT} + a_5\mathrm{U10m}$$

EIS

FT warms more than SST



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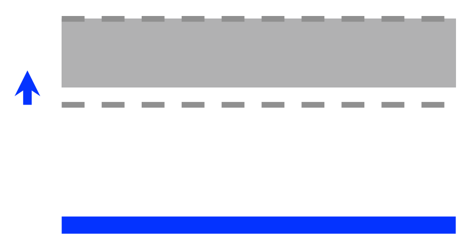

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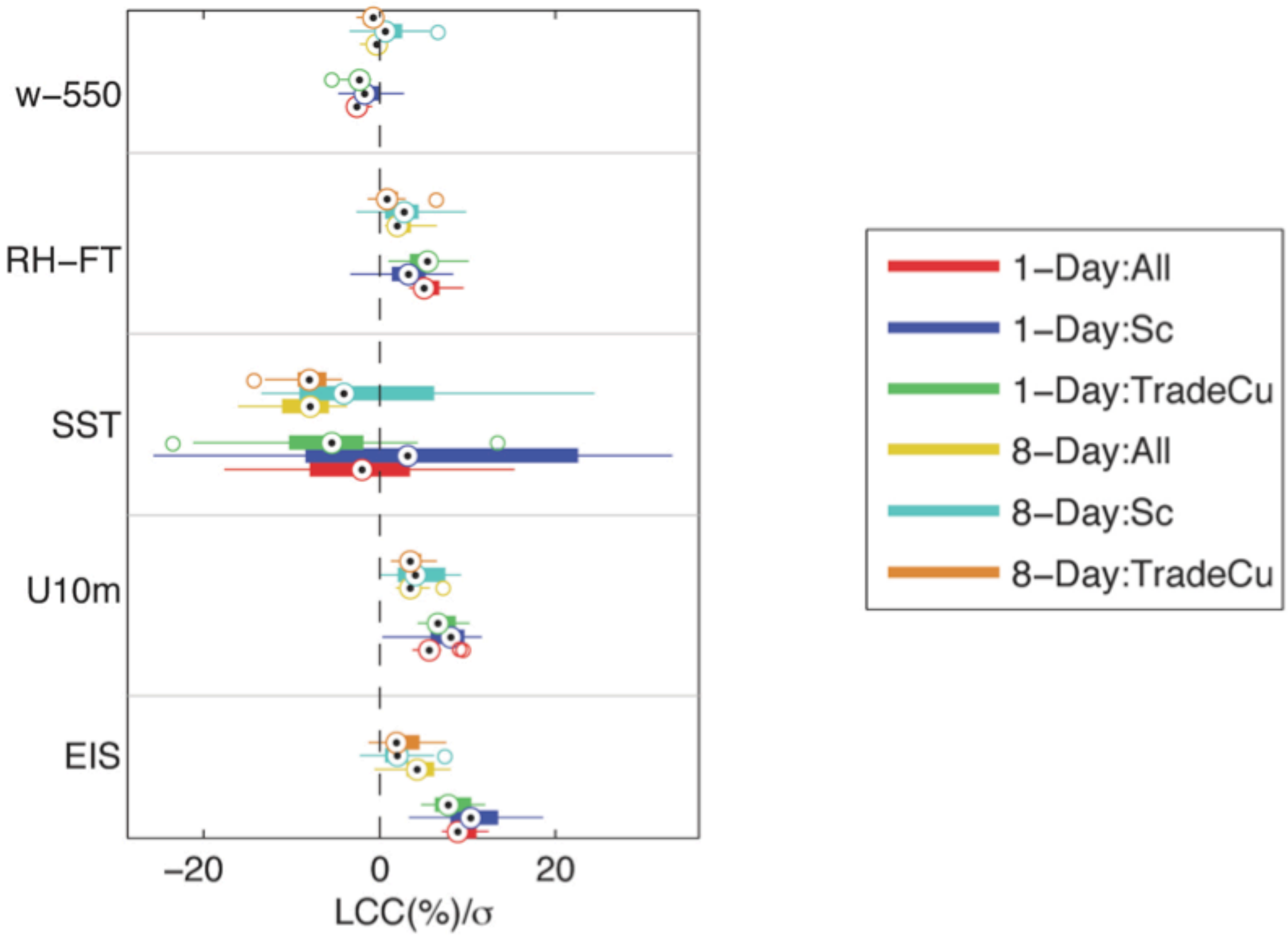
+ Data: MODIS, AIRS, ERA-Int.

- 2002-2014
- Timescale: 8-day mean, 1-day/instantaneous
- MODIS
  - 8-day mean: collection 6, Random overlap assumption
  - 1-day/instantaneous: collection 5.1, filter for scenes with no mid or high cloud
- AIRS
  - 8-day mean EIS and RHFT
- ECMWF ERA-Interim
  - 4xdaily data interpolated to local Aqua overpass time
- Composite by regime, season

Results: Multiple Linear Regression



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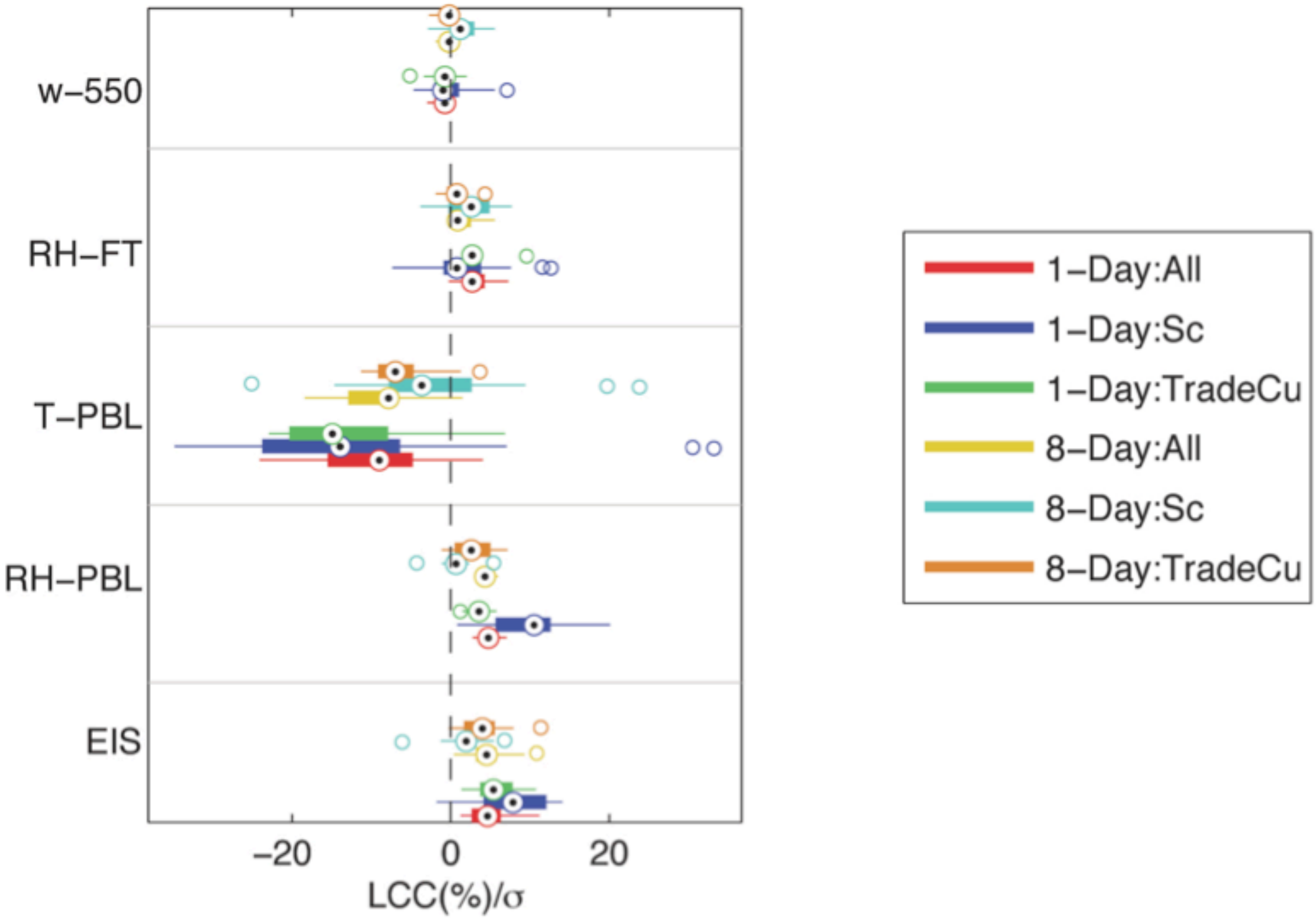
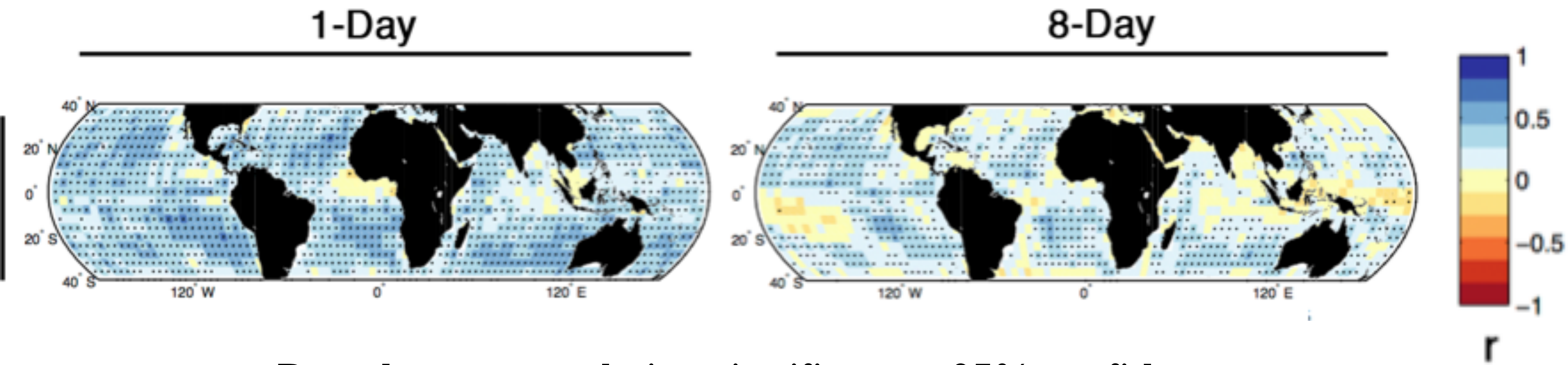


Quality of Regression

Correlation coefficient (r) between observed time series of LCC at each point and predicted LCC



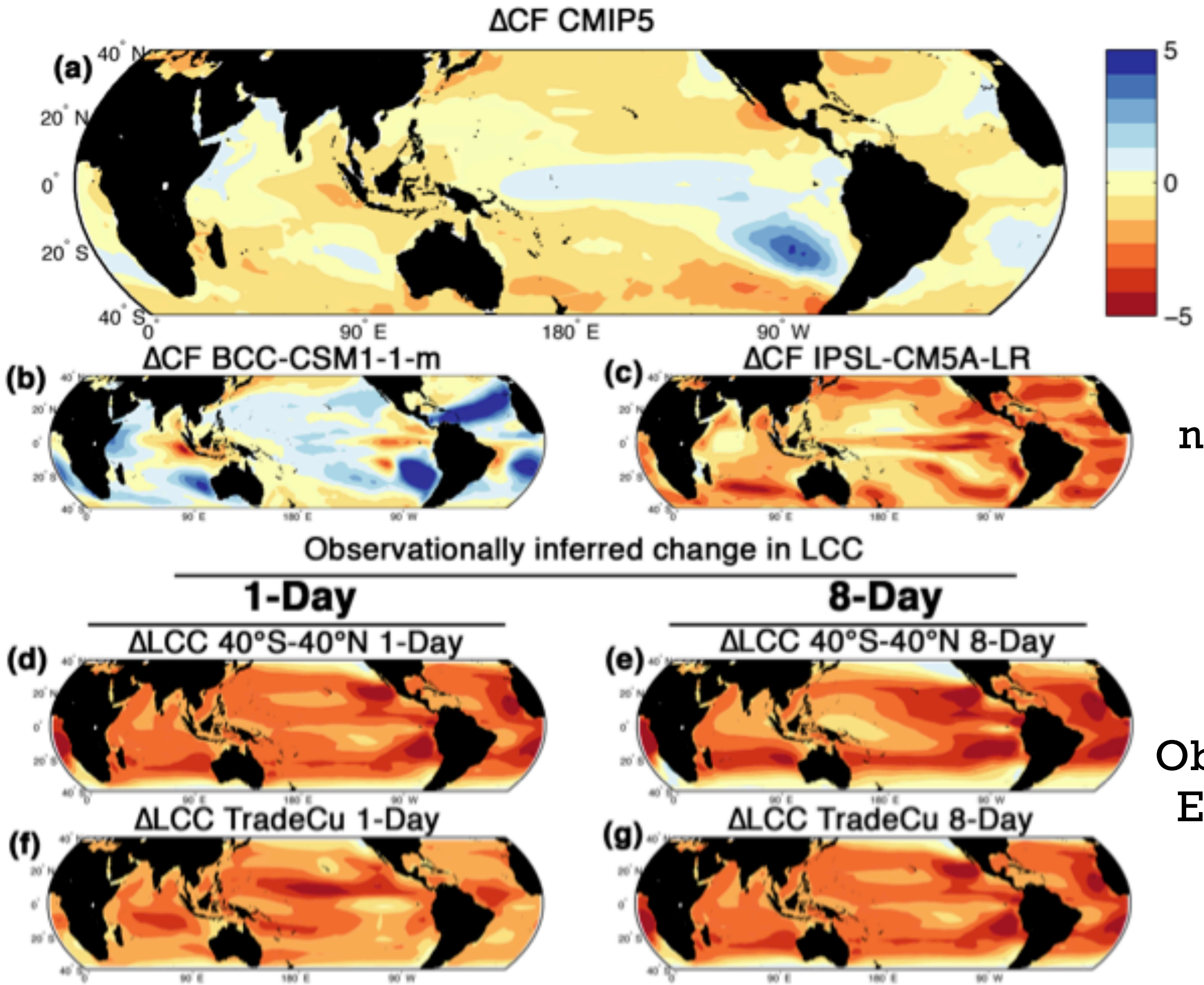
Dots denote correlation significant at 95% confidence

- Regression explains ~50% variance of observed LCF

Observational Estimates Resemble Models with large CF decrease

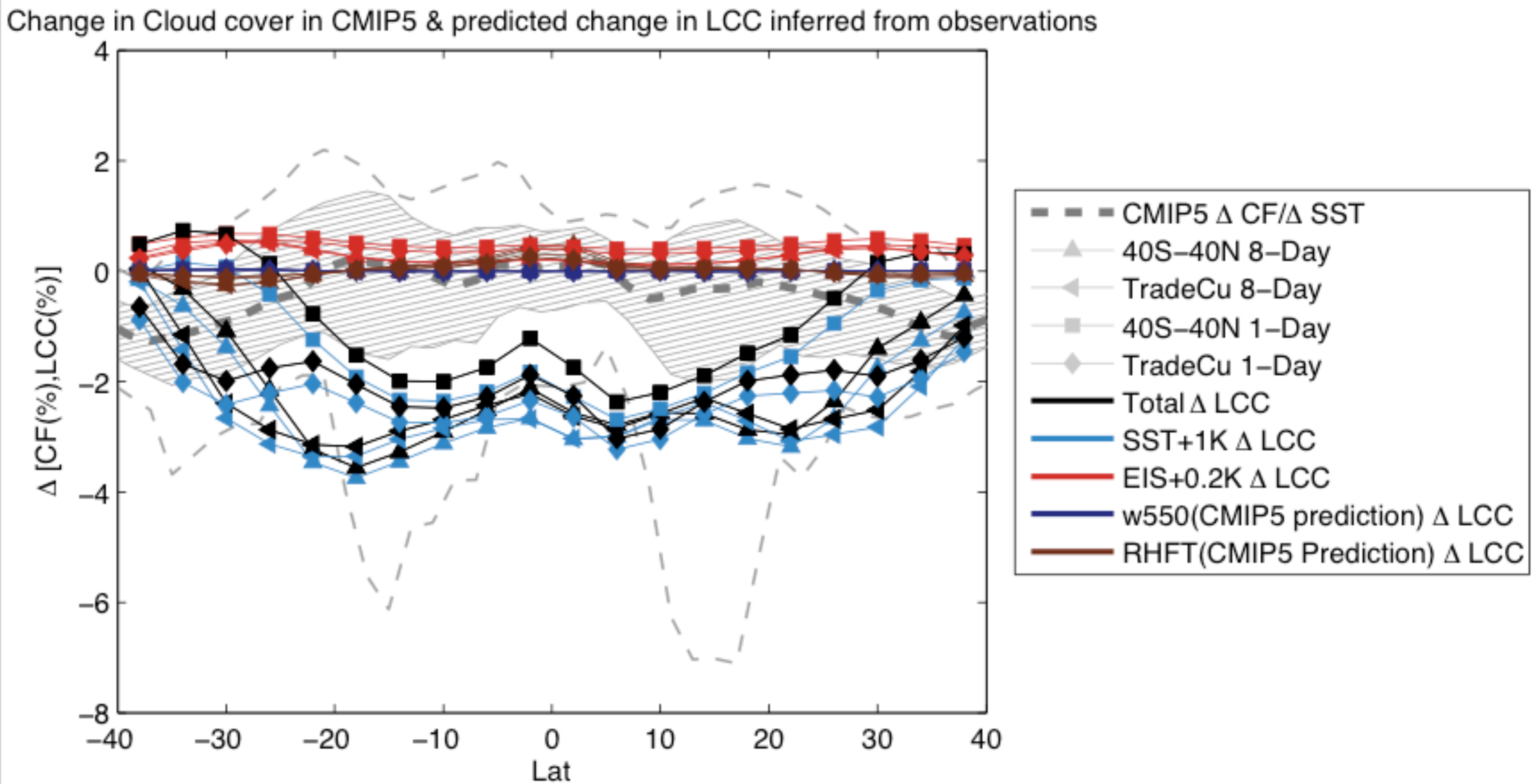
Most positive Δ CF

Most negative Δ CF



Observational Estimates of Δ CF

+ Δ SST most important large scale predictor for Δ LCF



+ Comparison with LES studies

- Observational estimate predicts ΔLCF dominated by ΔSST
- LES studies predict that ΔSST of leading order importance causing ΔLCF, but other predictors also important

+

Summary

- Lower LCF associated with
  - Warmer SST (+ SST)
  - Weaker Inversion (- EIS)
  - Drier Free Troposphere (- RHFT)
  - Stronger large scale subsidence (+ w550)
  - Weaker near-surface wind (- U10m)
- Warming estimate: LCF decreases by ~2-3% K^{-1}
- Observational estimates resemble GCMs with relatively large CF decrease with warming
- Sign of relationships consistent with previous observational studies (e.g. Myers and Norris, 2014, Myers and Norris, 2013) and LES studies (e.g. Bretherton et al., 2014, Blossey et al., 2013)

Extra Slides

Data

- MODIS:
  - 8 day-random overlap assumption, 1 day-filtered for scenes with not high cloud
  - Low clouds: CTP>680 hPa

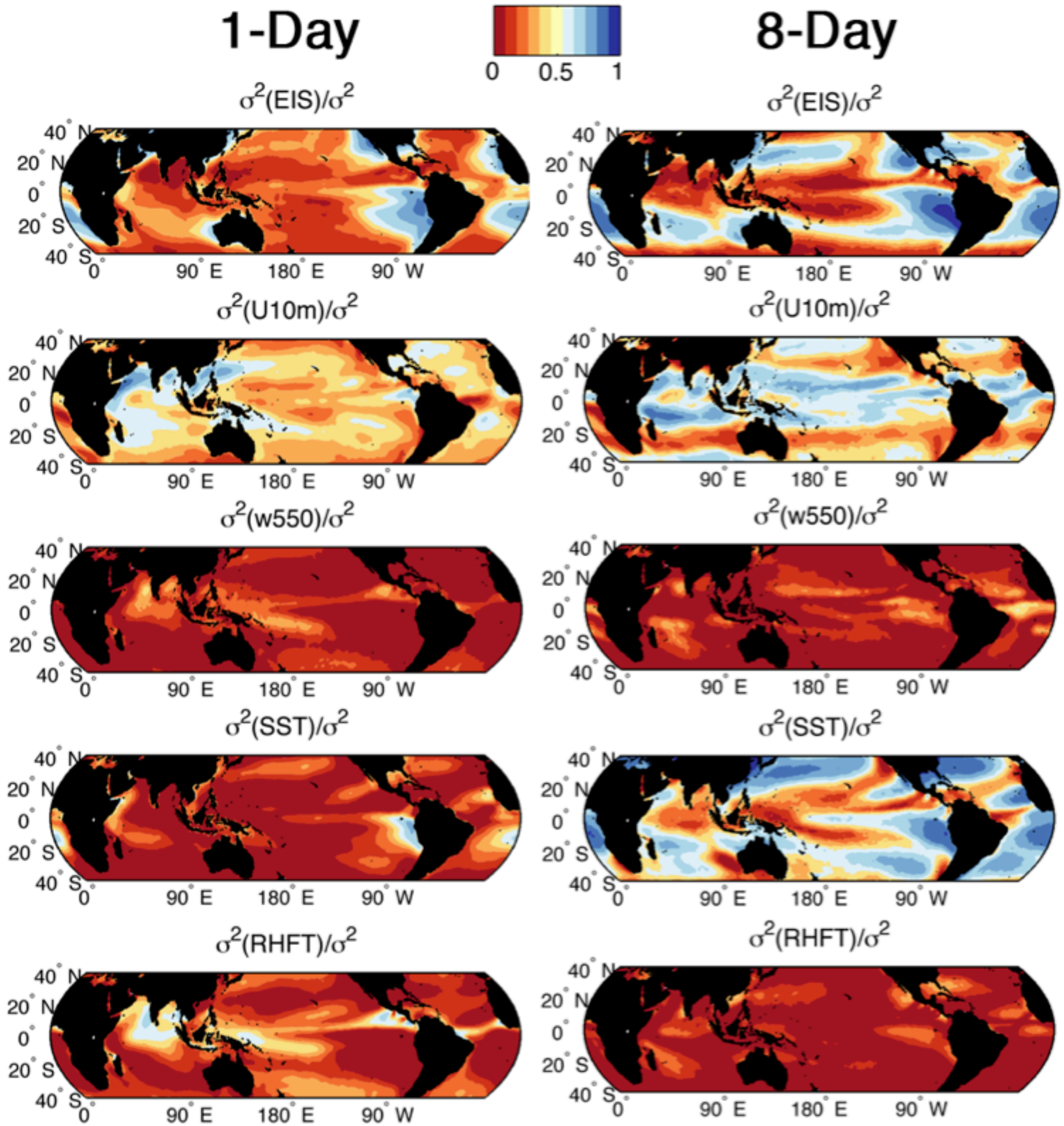
Large Scale Predictors

- EIS-stronger inversion traps moisture in PBL, enhanced cloud fraction
- Free Tropospheric RH-drier free troposphere enhances entrainment drying, reduced cloud fraction
- Large Scale Subsidence-weaker subsidence, higher inversion height, enhanced cloud fraction
- SST-expect negative correlation with LCC, possibly because of the enhanced liquid flux mechanism
- 10m Wind Speed-stronger wind stress enhances evaporation, enhanced cloud fraction
- Multiple Linear Regression:

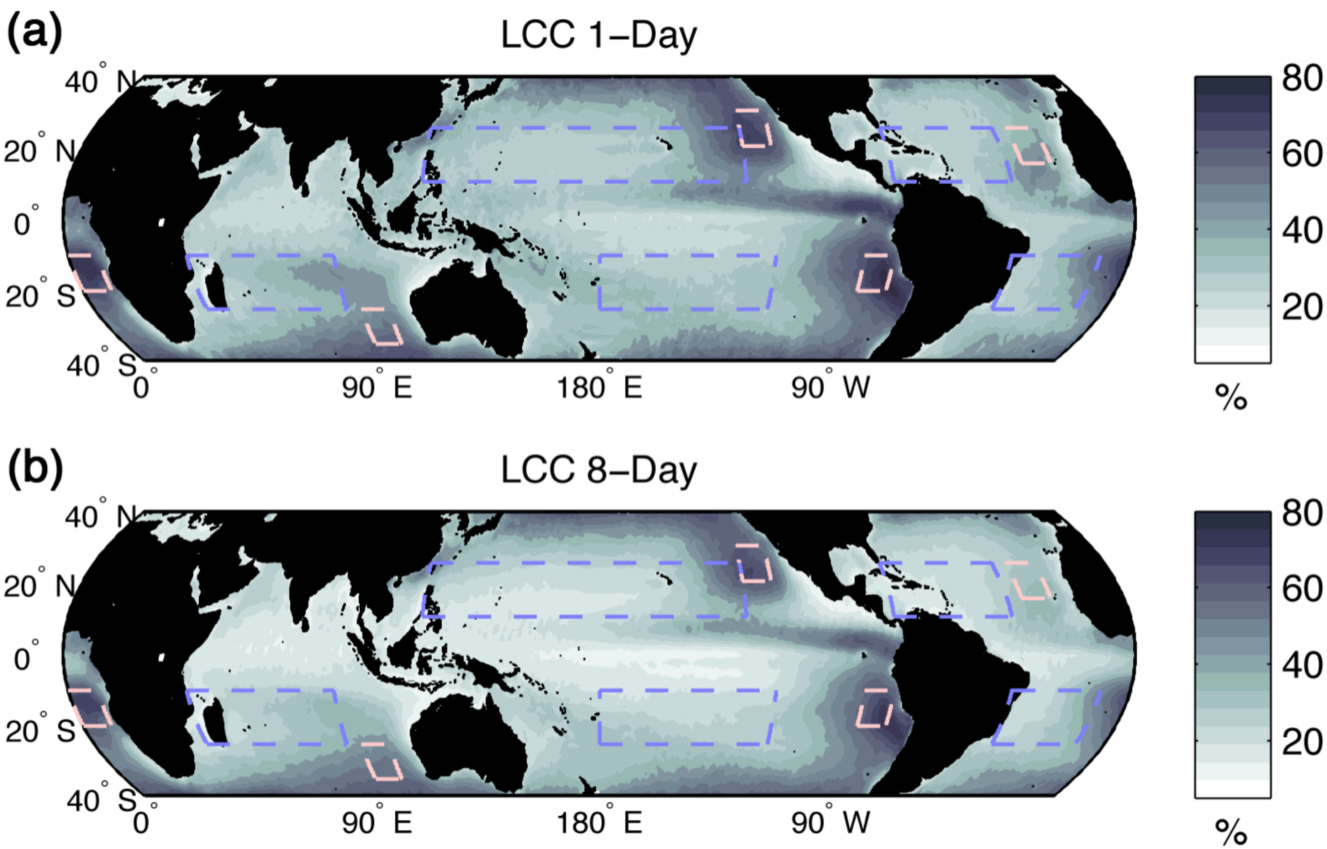
$$LCC = a_1 EIS + a_2 w550 + a_3 U10m + a_4 SST + a_5 RHFT$$

+

EIS/U10m Explain Large Amount of Variance



Composite by regime, season



Large Scale Predictors

- EIS
- Free Tropospheric RH
- Large Scale Subsidence
- SST
- 10m Wind Speed

- Multiple Linear Regression:

$$LCC = a_1 EIS + a_2 w550 + a_3 U10m + a_4 SST + a_5 RHFT$$

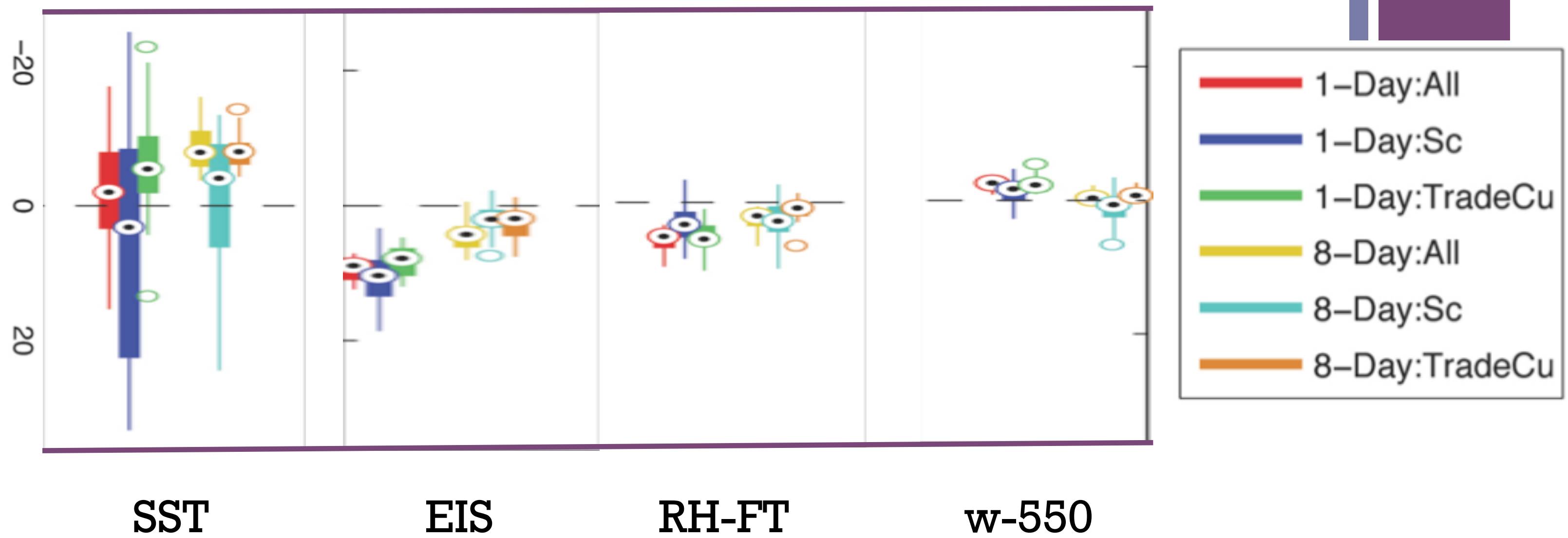
+ Comparison with Previous Observational Studies

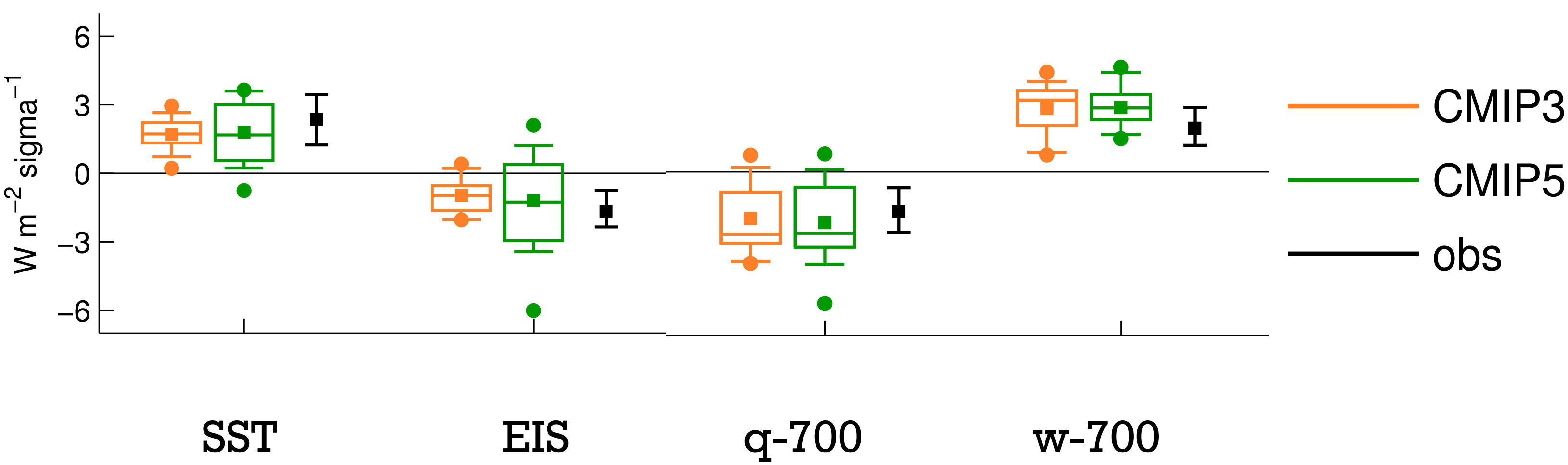
- Sign of regression coefficients consistent with previous observational studies (e.g. Myers and Norris, 2013, 2014)

Relationships Agree w/ Other Observational Studies

McCoy et al., in prep.

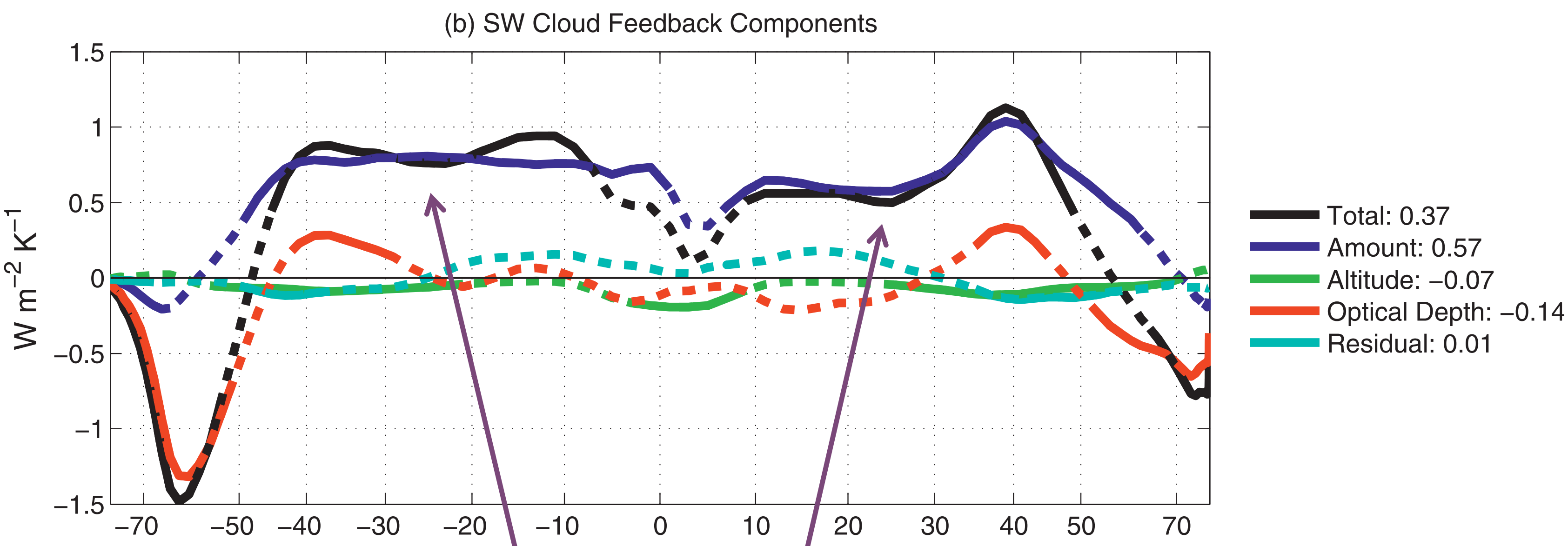
Larger CF/ More Negative SW CRE





Myers and Norris, 2014

Cloud Fraction Changes Dominate in Subtropics



Cloud Fraction changes dominate SW cloud feedback in the Subtropics

Zelinka et al., 2011

Quality of Regression

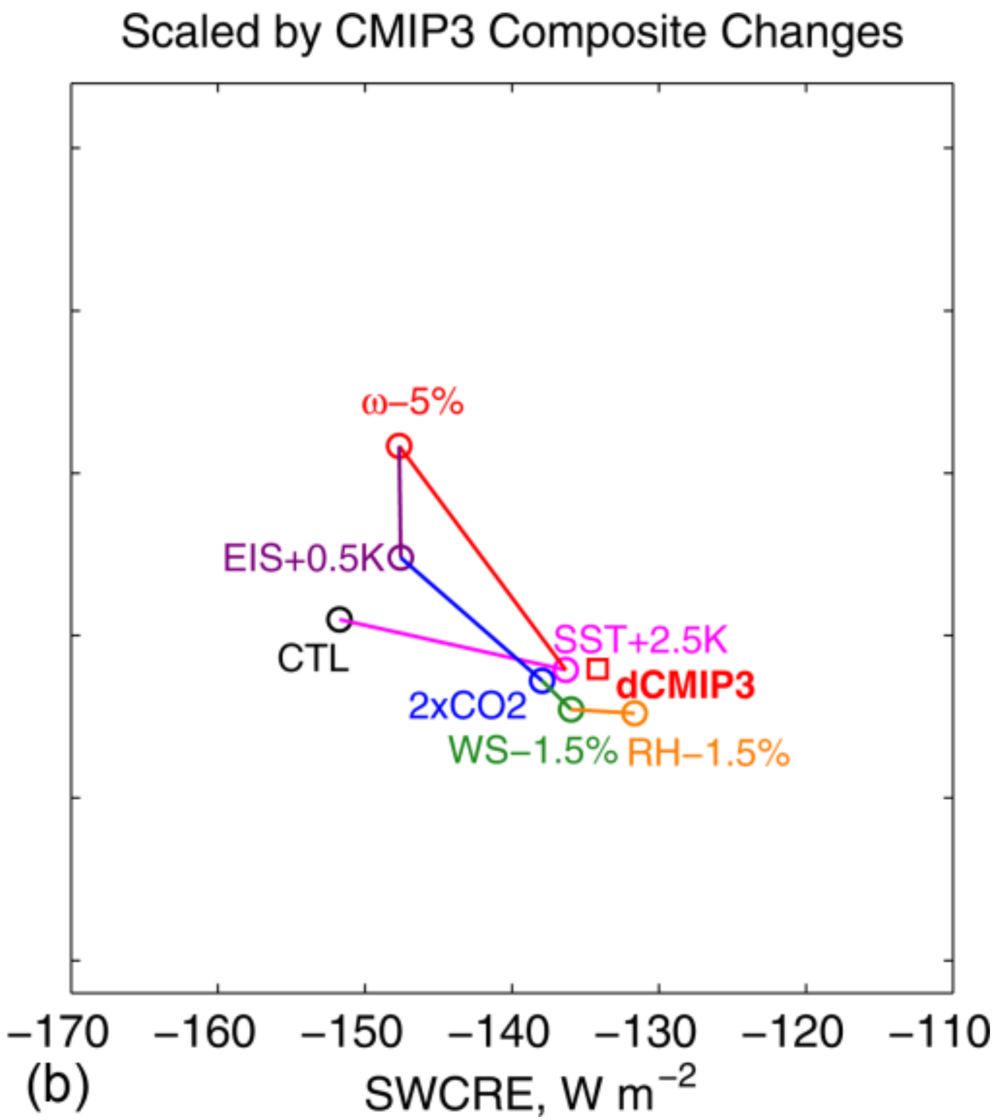
- Multiple Linear Regression reproduces ~44% of variance over 40° S-40° N
- Generally higher correlations in the 1-day/instantaneous data set than the 8-day mean data set
- Negative correlations in Canarian and Californian stratocumulus regions

Results

- Find that Low Cloud Fraction increases with
  - Weaker large scale subsidence
  - Larger Free Tropospheric RH
  - Larger near-surface wind speed
  - Larger EIS
- Climate change estimate: decreased Low Cloud Fraction throughout 40°N-40°S with SST+1K

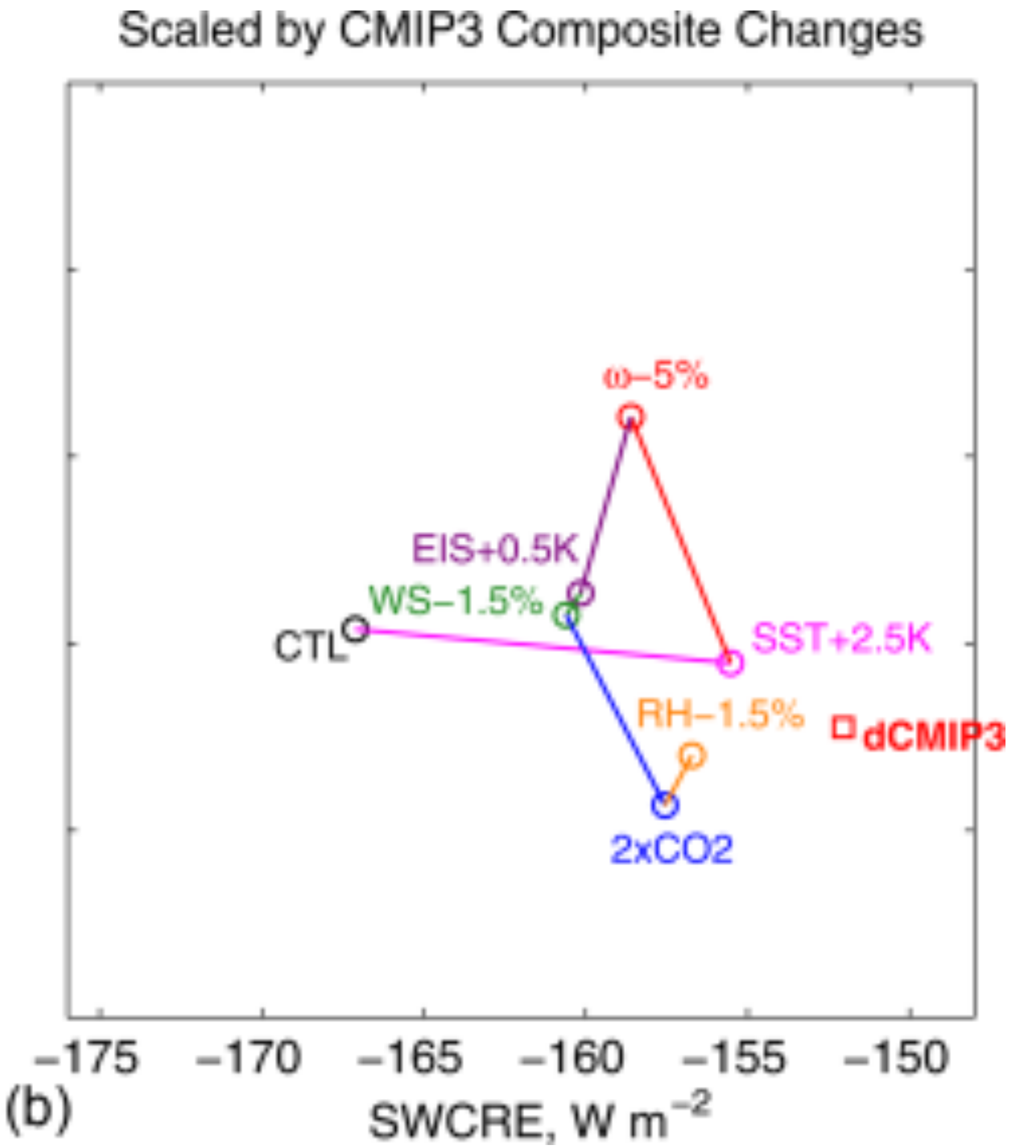
+ LES: Stratocumulus

Inversion height



+ LES: Cumulus under Sc

Inversion Height



LES: Trade Cumulus

Inversion height